AD/A-000 709

# CHARACTERIZATION OF GALVANIZED SHEET STEEL FOR AUTOMOTIVE VEHICLE BODIES

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Frankford Arsenal
Philadelphia, Pennsylvania

August 1974

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## REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
FA-TR-74021

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER
AD/A-000 709

4. TITLE (and Subtitle)
CHARACTERIZATION OF GALVANIZED SHEET STEEL FOR AUTOMOTIVE VEHICLE BODIES

5. TYPE OF REPORT & PERIOD COVERED
Research report

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
F. Pearlstein
A. Gallaccio

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
FRANKFORD ARSENAL
ATTN: SARFA PDM-A
Philadelphia, PA 19137

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
AMCMS Code: 4933.04.4261
DA Project: MMFP-A045

11. CONTROLLING OFFICE NAME AND ADDRESS
U.S. Army Tank-Automotive Command TACOM
Warren, MI 48090

12. REPORT DATE
August 1974

13. NUMBER OF PAGES
40

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

The technical assistance of Mr. Harry J. Addison, Jr., in arranging for and in monitoring the welding tests, is gratefully acknowledged.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Galvanized steel
Zinc coating
Minimized spangle
Galvanneal
Coating thickness measurements
Corrosion resistance
Paint adhesion
Welding
Formability
Stripping

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Commercially available galvanized steel sheet materials, obtained from several sources, and representing zinc coatings of conventional spangles, minimized spangles, and of diffusion alloy (galvanneal), were characterized for quality and performance.

Thicknesses of the galvanize coatings were determined by chemical stripping (procedures for which are offered), by microscopic examination

20.(Cont'd.) of cross-sectioned specimen, and by magnetic and eddy-current measuring devices. These methods were compared for reproducibility and for selection of a method suitable for general use. Corrosion resistances of the galvanized steels were determined following specific periods of exposure of specimens in five percent salt-fog environment.

The galvanized sheets having a minimum coating thickness of 14 μm, and averaging about 22 μm, resisted corrosion in salt-fog exposure for 72 hours. Since longer exposure, e.g., 96 hours, gives evidence of incipient rusting, the 72 hour period without any evidence of rusting of the steel substrate was recommended suitable for quality control purposes. The adhesion and protective value of a particular paint system on the galvanized materials are discussed. Bead and spot welding of the galvanized sheets were successfully performed; typical and feasible welding procedures are described. The amenability of the various materials to forming or shaping without flaking of, or other damage to, the coating was demonstrated.

Conclusions regarding the suitability of the test methods and their adoption generally are offered. Recommendations for: use of the materials, application of preferred thickness measuring methods, and acceptance of corrosion resistance qualifying criteria, are presented.

## CODE SHEET

Galvanized Steel sheet (1.25 Commercial)[7] used in this investigation, and source of the materials.

| Code | Supplied By | Type |
|---|---|---|
| A | Armco Steel Corporation | Minimized spangle |
| B | Bethlehem Steel Corporation | Minimized spangle |
| G | Bethlehem Steel Corporation | Standard spangle |
| ES | U.S. Steel Corporation | Minimized spangle, smooth, (rolled) |
| GA | U.S. Steel Corporation | Galvanneal |
| U | U.S. Steel Corporation | Minimized spangle |

[7] ASTM, Standard Specification for "General Requirements for Delivery of Zinc-Coated (Galvanized) Iron and Steel Sheets, Coils, and Cut Lengths Coated by the Hot-Dip Method", ASTM Designation A525-67.

TABLE OF CONTENTS

## List of Tables



## List of Illustrations

List of Illustrations - Cont.

## INTRODUCTION

Several years ago, the U.S. Army Tank and Automotive Command (TACOM) initiated a program for the purpose of acquiring information for reducing corrosion damage to, and for maintenance of, automotive vehicle bodies.[1] The specific aim was to establish for military vehicles the feasibility of employing metal-coated sheet steel in place of conventional steel sheet to retard corrosion induced by aggressive agents, e.g., moisture and salts, in the event that damage of the protective paint finishes occurred.

Commercially available galvanized and aluminized sheet steel were used in fabricating body sections of two general purpose trucks. The coated metal sheets were employed to replace ordinary steel sheet in fabricating certain body sections, to reduce vulnerability to corrosion. Galvanized sheet was used in one truck and aluminized sheet in the other. The coated sheets were of #14, #16, and #20 gauges. After fabrication and painting, the trucks were exposed, in service, in the Panama Canal Zone.

Concurrent with the field test of the vehicles, the U.S. Army Coating and Chemical Laboratory, at Aberdeen Proving Ground, Maryland, by request of TACOM, conducted an investigation of various paint systems applied to galvanized and aluminized sheet materials used in the vehicles, and of zinc-rich coating systems applied to the coated steels, and to steel which served as a control. The panel specimens were exposed at marine, open-field, and rain-forest sites in the Panama Canal Zone. The results of this finishing study have been reported.[2]

On the basis of results acquired after more than two years' testing of the vehicles in the field, and the findings of the Coatings and Chemical Laboratory, the Tank and Automotive Command made the decision to use galvanized sheet in specific areas of new vehicle bodies. Consequently, TACOM decided that a specification would be needed to suitably characterize the desired quality of the galvanized sheet and to define the test procedures to be applied for qualifying the material.

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[1] U.S. Army Tank and Automotive Command, Program to CCL - Metallic Coated Steels and Metal-Rich Coatings for Automotive Vehicle Bodies for Evaluation in Panama Canal Zone, 1965.

[2] Sandler, M.H., "Effect of Metallic Coatings and Zinc-Rich Primers on the Performance of Finishing Systems for Automotive Steel", CCL Report 285, U.S. Army Aberdeen Research and Development Center, Coating and Chemical Laboratory, Aberdeen Proving Ground, MD, September 1970.

In response to a request from TACOM[3] to this installation, a proposal[4] was submitted for developing performance criteria and for the preparation of a proposed specification applicable to commercially available galvanized steel sheet for use in the fabrication of bodies for wheeled vehicles. An addendum[5] to that proposal was also offered to encompass weldability and the influences of welding on the corrosion of galvanized steel. The proposal was approved and supported by TACOM. This report, and a specification[6] are in fulfillment of the investigation conducted for TACOM.

## OBJECTIVES

The purposes of this investigation are as follow:

1. To establish the basis metal resistance to corrosion of galvanized steel sheet, of various commercial sources, in unpainted and painted conditions, by means of laboratory accelerated tests.

2. To determine the effects of forming or bending the galvanized sheet, on the corrosion resistance at formed areas.

3. To determine the weldability of galvanized steel sheet and the effects of welding on the corrosion at or adjacent to the weld seam.

4. To define the test conditions and inherent performance characteristics of the galvanized sheet steel, and apply these as criteria in preparing a specification for galvanized steel for vehicle bodies.

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[3] Letter, U.S. Army Tank and Automotive Command to Frankford Arsenal, Subject: Steel, Galvanized, for Wheeled Vehicles (Project MFFP-A045). Request for proposal, 1970.

[4] Proposal - Delineation of Preformance Requirements of Galvanized Sheet Steel for Use in Wheeled Vehicle Bodies, Frankford Arsenal to U.S. Tank and Automotive Command, October 1970.

[5] Proposal Addendum I - Extension of Scope of Proposal, Letter to U.S. Army TACOM, 3 March 1971.

[6] Military Specification, MIL-S-48403 (MU) "Steel Sheet, Hot-Dip, Zinc Coated (Galvanized), Minimum Spangel, for Automotive Vehicle Body Use", 11 May 1973.

## MATERIALS

Galvanized steel sheet, #16 gauge, 1.25 Commercial galvanize, was selected for purposes of this investigation.[7]

Descriptions of the galvanized sheet and welding rod materials, and the paint systems, employed in this investigation follow:

Galvanized Steel Sheet, #16 gauge, 1.25 Commercial Galvanize

| Code | Description of Coating |
|---|---|
| A | Minimized Spangle |
| B | Minimized Spangle |
| G | Standard Spangle |
| ES | Minimized Spangle, Extra Smooth (rolled) |
| GA | Galvanneal |
| U | Minimized Spangle |

Paint System

| Paint | Specification | Thickness Applied |
|---|---|---|
| Wash Primer | MIL-P-15328 | 10 ± 2.5 μm* |
| Primer | MIL-P-8585 (TT-P-666) | 18 ± 2.5 μm |
| Enamel | TT-E-529 | 25 ± 5 μm |

*25 μm = 0.001 inch

Welding Rod

| Method of Welding | Rod (Electrode) |
|---|---|
| Gas Metal Arc | AWS E 7053 (Hobart 23), 0.035" (.89 mm) diameter |
| Shielded Metal Arc | E 6012 (Westinghouse ZP12), 1/8" (3.13 mm) diameter |

[7] ASTM, Standard Specification for "General Requirements for Delivery of Zinc-Coated (Galvanized) Iron and Steel Sheets, Coils, and Cut Lengths Coated by the Hot-Dip Method", ASTM Designation A525-67.

## EXPERIMENTAL PROCEDURES

After shearing galvanized steel to appropriate size specimens for testing, all specimens were vapor degreased in trichlorethylene. A cheese-cloth wad, soaked in acetone, was used to remove any insoluble residue left on the surface after degreasing.

### Visual Surface Characterizations

The galvanized steel from the various commercial sources was examined for presence and dimension of spangles (zinc crystal faces). Freedom of the surface from irregularities such as prominent crystal ridges or nodules was determined by movement of the finger tips over the surface.

### Stripping Zinc Coating for Weight and Thickness

Weighed specimens (5.1 cm x 5.1 cm) of galvanized steel sheet from each source were immersed in an appropriate acid solution to remove the zinc coating. The stripped specimens were rinsed in water, neutralized in 100 g/l $Na_2CO_3$ at 25° C, rinsed with dry acetone, and reweighed. The average thickness of zinc on each material was calculated from the weight loss measurements as follow:

$$\text{Thickness, } \mu m = \frac{\text{weight loss, g} \times 10^4}{52\ cm^2 \times 7.14\ g/cm^3} = 0.027 \times \text{weight loss in mg}$$

Note: Specific gravity of coating taken as pure zinc, i.e., 7.14 $g/cm^3$

Galvanized steel specimens, Code G, were immersed into concentrated HCl + 1 g/l $Sb_2O_3$ or into 50 percent (volume) HCl, with or without the addition of 10 ml/l Rodine 50,* for three successive one minute periods to compare effectiveness of the solutions for removal of zinc coating and the degree of basis metal attack produced.

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*Proprietary inhibitor, Amchem Products Inc., Ambler, PA.

Galvanized steel specimens from several commercial sources were immersed into 500 ml of 50 percent (volume) HCl, and the time of stripping estimated by cessation of vigorous gassing on the specimen surface. The temperature rise of the solution after stripping of two or three specimens at a time was also determined.

Galvanized steel specimens, Code A, were immersed individually and successively in 200 ml of 50 percent (volume) HCl at 25 ± 2C for a two minute period. The number that could be stripped within a two minute period was determined in order to ascertain the surface area of galvanized steel that could be effectively stripped by a given volume of acid.

## Thickness of Coating - Direct Measurements

Instrumental measurements were made at five points on each side of a panel but not closer than 1.3 cm from an edge. The average coating thickness on each side of a specimen was determined by averaging the thickness found at the five points. Microscopic measurements were made on the cross-section of selected galvanized steel specimens at 500X magnification. Zinc coating thickness measurements made on 5.1 cm x 5.1 cm specimens obtained by stripping, by microscopic examination of cross-sections, and by magnetic gage* or eddy current** instruments, were compared.

## Paint Adhesion

Four sets of quadruplicate galvanized panels (10.2 cm x 15.3 cm), Codes A, B, G, and U, were vapor degreased and solvent cleaned. These were then spray coated with the following paint systems:

Wash primer, MIL-P-15328 (average dry-film = 12.5 μm)

Zinc chromate primer, MIL-P-8585 (average dry-film = 17.9 μm)

Semi-gloss enamel, TT-E-529 (average dry-film = 25.4 μm)

*Magne-Gage, American Instruments Company

**Dermitron, Unit Processes Company

After allowing it to dry in air, for 72 hours, the paint coating on three sets was evaluated for adhesion to the galvanize surface using the knife and the tape tests. Tape tests were also conducted following immersion of coated specimens in water for 24, 48, or 72 hours. Visual examinations were also conducted on specimens after being in water for 1000 hours at room temperature, in aerated water at room temperature, or in aerated water at 35°C.

The paint system on several panels from each set was air-dried seven days, after which the specimens were placed in a salt-fog cabinet for 1000 hours for paint system defects or corrosion of the galvanized steel.

## Corrosion Resistance

Galvanized steel panels (10.2 cm x 15.3 cm and 10.2 cm x 30.5 cm) were exposed to five percent neutral salt spray* at an angle of 17° from the vertical. Examinations were made at 24 hour intervals. Corrosion failure was deemed to have occurred when basis metal attack was evident by observation of distinctive red-orange rust spots. Diffuse yellow stains in the white zinc corrosion products was not considered as failure. The relationship between time for corrosion failure and coating thickness of commercial galvanized steel from several sources was determined. The effect of bare (sheared) edges on corrosion behavior was determined by comparing bare-edge panels to panels with waxed-coated edges. Also exposed to salt spray were panels that had been subjected to the bend test, described below. The bent area was at the top during exposure. Panels painted as described under "Paint Adhesion" were also exposed to salt spray.

## Inter-Laboratory Tests - Corrosion Resistance and Coating Thickness

Galvanized steel panels (10.2 cm x 30.5 cm) from four commercial sources were prepared in quadruplicate. Each panel was sheared in half to provide two sets of 10.2 cm x 15.3 cm panels. One set was tested at Coatings and Chemical Laboratory (CCL), Aberdeen Proving Ground and one set at Pitman-Dunn Laboratory (PDL), Frankford Arsenal,

*ASTM Standard Method B117, Salt Spray (Fog) Test.

for corrosion resistance. The panels were marked so that the identity of the original panel was retained and the same side was tested by each laboratory. Furthermore, the salt spray exposure test was conducted with the sheared edge (middle of original panel) up. The panels were then exposed to salt fog for a 96 hour period and examined for attack of the basis metal. Coating thicknesses were measured independently at CCL and at PDL, using several types of instruments. The measurements were performed on each side of the same specimens (5.1 x 5.1 cm), at each station, following the procedure described above. The results of the two laboratories were compared.

## Formability (Bend Test)

Galvanized steel panels (10.2 cm x 30.5 cm) from several commercial sources, held in a heavy duty, smooth-jawed vise, were bent at about 12 cm from one end through an angle of about 130°. The vise was then used to squeeze the bent specimen to a 180° angle bend with the sides of the sheet separated at the bend area by a width four times the thickness of the metal, i.e., the inside radius of the bend was twice the thickness of the sheet. The outer bent area (stressed in tension) was examined at 7X magnification for cracking or flaking of the deposit. Some of the panels were further compressed until the inside radius of the bend was only one half the thickness of the sheet and re-examined at 7X magnification.

## Welding

The galvanized sheet materials were degreased in trichlorethylene and dried prior to welding.

Galvanized panels of materials Codes A, B, G, U were joined by resistance spot welding along a 3/4 inch overlap of the long edge. Other specimens were joined by arc welding as an edge fillet along a long-edge overlap of 3/8 inch. The same was done using the shielded metal arc welding processes. The joint configurations are shown in Figures 1 and 2.

The resistance spot welding was done on a 150 KVA single phase welder with a synchronous precision welding control using the following schedule, in accordance with AWS C 1.3-70, Recommended Practice for Resistance Welding Coated Low Carbon Steel.

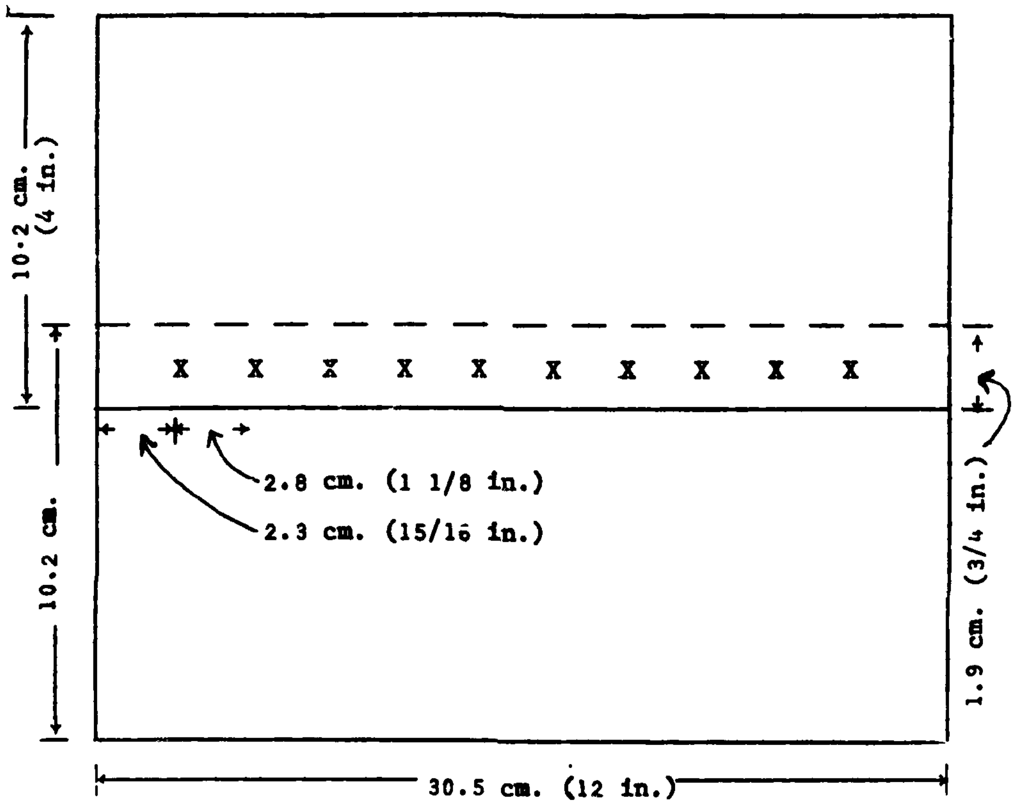



Figure 1. Resistance Spot-Welded Panels, Galvanized Steel

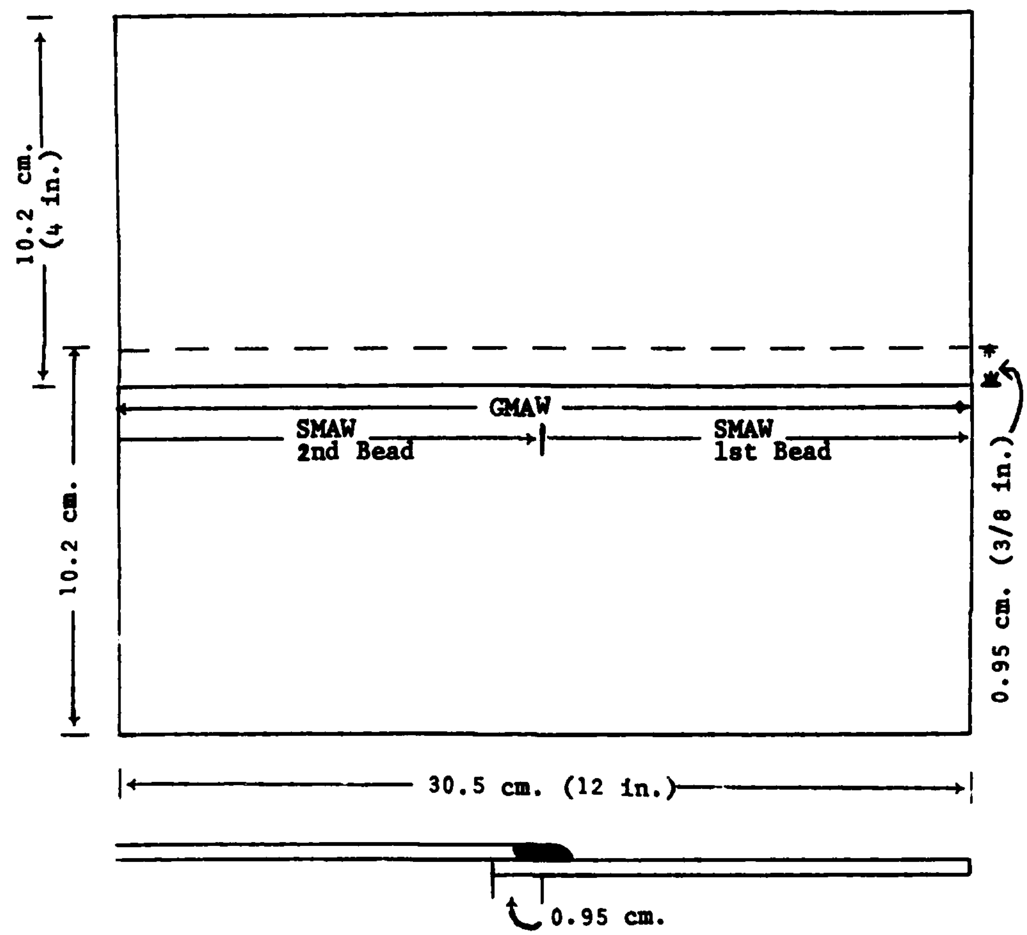



**Figure 2. Gas-Metal and Shielded-Metal Arc Welded Panels - Galvanized Steel**

| | |
|---|---|
| Electrode | 15.9 mm (5/8") diameter RWMA, Gr. A, Cl. 2 (M28) |
| Electrode | 6.4 mm (¼") diameter 120° truncated cone |
| Electrode force | 454 kg. (1000 lbs.) |
| Weld time | 2? cycles |
| Weld current | 13200 to 14500 amperes (rms) |
| Squeeze time | 20 cycles |
| Hold time | 50 cycles |
| Weld overlap | 19.1 mm (3/5") |
| Weld spacing | 28.6 mm (1 1/8") |
| Weld diameter | 6.1 mm (0.24") (Min.) |
| Weld strength | 1135 kg. (2500 lbs.) (Min.) |

The gas metal arc welded panels were prepared using the short circuiting drop transfer technique and an automatic setup with $CO_2$ shielding gas. The power source was a 300 ampere DC rectifier. A copper back-up plate was used to minimize loss of zinc.

A lap fillet weld was made as shown in Figure 2 using the following schedule:

| | |
|---|---|
| Current | 110-120 amperes DC |
| Arc coltage | 22.5 volts |
| Shield gas and flow | $CO_2$ ca. $1m^3$/hr. (35 cfh) |
| Electrode size | 0.87 mm 0.034" diameter |
| Electrode size | AWS E 70S3 (Hobart 25) |
| Travel speed | 76 cm (30") per minute |

Panels were sprayed with an anti-spatter compound of an aerosol type. Gas metal arc welded panel B was not costed with anti-spatter compound prior to welding.

Shielded metal arc welded panels were made similar to those for the gas metal arc welding. The panel geometry in Figure 2 was used for these welds. The welding schedule follows.

| | |
|---|---|
| Current | 90 amperes DC |
| Arc voltage | 22 volts DC |
| Electrode | ca. 3.2 mm (1/8") diameter, E 6012 (Westinghouse ZP 12) |
| Travel speed | 20.3 cm (8") min. (approximate) |

A 300 ampere DC rectifier was used for arc welding.

Panels were made by tack welding at one end, and the fillet weld which was started in the middle continued toward the tack-welded end. A second pass was started at the other edge and welded to the middle to overlap the first bead.

All panels were coated with an anti-spatter compound as an aerosol spray.

## RESULTS AND DISCUSSION

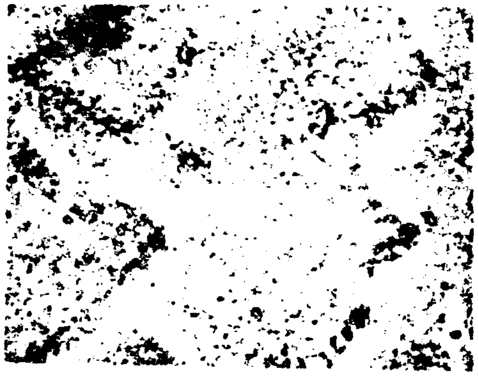
### Surface Characterization

The surface characteristics were determined for galvanized steel from several commercial sources. The following observations were made of the various materials illustrated in Figure 3.

Code A (minimized spangle): The crystalline structure of the surface could not be discerned by the unaided eye. The surfaces were very smooth to the touch.

Code B (minimized spangle): A crystalline structure could barely be made out by the unaided eye and the crystal size averages about one mm diameter. The surfaces were quite smooth to the touch.

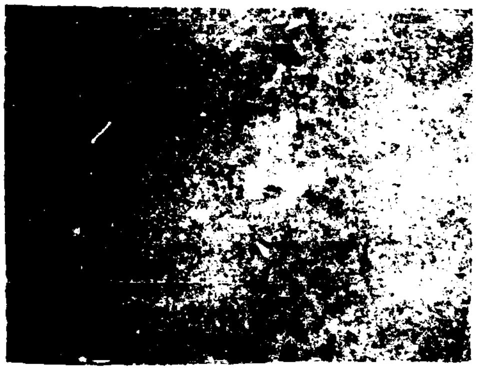
Code G (conventional galvanize): Large zinc crystals (spangles), typical of galvanized steel, were present. The average spangle size was between one and 1.5 cm in diameter. One side of the sheet had prominent crystal ridges, readily detectable by fingertips brushing the surface. The opposite side of the sheet also had large spangles but was quite smooth to the touch.



Code A

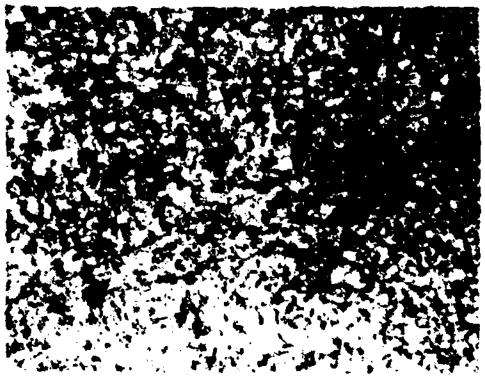
Code B

Code G



Code ES

Code GA



Code U

Figure 3. Characteristic Surfaces of the Galvanized Sheet Steels

Code ES (minimized spangle - rolled): Crystal faces were not visible and the surfaces were very smooth to the touch.

Code GA (galvanneal): The surface had a more uniform, gray-matte appearance than any of the other sheets examined and was very smooth to the touch.

Code U (minimized spangle): On one side of the sheet, a crystalline structure was not discernable but on the other side, spangles were evident. Some areas of the material examined had crystals about one mm in diameter, while other areas had spangles as large as 5 mm in diameter. The surfaces were considered smooth to the touch although the crystal pattern was barely detectable by touch at the areas of larger crystal size.

The brightest appearing surfaces were those with the most prominent crystal structure, i.e., Code G and Code U (areas of larger crystal size). The other materials were grey in appearance with varying texture. Material Code A, ES and GA were smoothest (Figure 3). One side of the Code G material was quite smooth and could undoubtedly be painted without revealing the crystalline structure of the surface through the organic coating. However, the other side of Code G would be expected to exhibit the crystal structure through the paint coating. The larger crystals observed on Code U material would also probably be discernable through the paint film.

## Removal of Zinc Coatings

The results of stripping tests in several acid solutions are shown in Table I.

TABLE I.

Stripping of Galvanize Coatings in Acid Solutions
Weight Loss of Specimens, Successive One Minute Periods, mg

| Solution | Period 1 | Period 2 | Period 3 |
|---|---|---|---|
| HCl (conc.) + 1g/l $Sb_2O_3$ | 884 | 1 | 1 |
| 1:1 HCl | 961 | 3 | 1 |
| 1:1 HCl + 10 ml/l Rodine 50 | 183 | 221 | 573 |

It is evident that the first two stripping solutions listed in Table I were effective for removing the entire zinc coating during the first one minute immersion period. The presence of the proprietary pickling inhibitor, Rodine 50, substantially reduced the rate of attack of zinc in the HCl solution. From the standpoint of simplicity and economy, the uninhibited acid solution was suitable for stripping zinc coatings from galvanized steel and all additional stripping tests were conducted with this solution.

The approximate stripping time for galvanized steel and the effect of stripping on bath temperature are shown in Table II. The specimens were immersed in groups of two or three in 500 ml of solution.

TABLE II.

Stripping Time and Solution Temperature Rise
During Stripping of Galvanized Steel in 50 Percent (vol.) HCl

| | Solution Temp $^{o}$C | | Approximate Stripping Time, Seconds | | | | |
|---|---|---|---|---|---|---|---|
| | | | Code | | | | |
| Test # | Start | Finish | A | U | G | ES | GA |
| 1 | 20 | 24 | 35 | 30 | 28 | | |
| 2 | 24 | 27 | 38 | 30 | 24 | | |
| 3 | 27 | 30 | 47 | 20 | 47 | | |
| 4 | 30 | 31 | | | | 30 | 61 |
| 5 | 20 | 24 | 70 | 33 | 90 | | |

It can be seen from Table II that the last group of specimens, Test #5, required a generally longer immersion time for complete stripping than the specimens in Test #1, at the same bath temperature, indicating that some bath depletion had resulted from use. The temperature of the solution generally increased three to four degrees during stripping. Thus, a three to four degree C increase in temperature can be expected by stripping of 312 $cm^2$ of the galvanized steel per liter of solution. It is probably not advisable to permit more than a five degree increase in temperature during stripping and thus the area of 1.25 Commercial galvanized steel to be stripped at one time should not exceed about 350 $cm^2$ per liter of solution. The temperature of the stripping solution should be kept below about 30$^{o}$C to prevent excessive attack on the basis metal.

Successive specimens of Code A material were immersed two minutes in a single 200 ml solution of 50 percent (volume) HCl, maintained at 25°C ± 2°C. It was found that 10 panels were completely stripped during the two minute immersion, but the 11th had traces of deposit remaining. The 12th panel also had a small amount of zinc coating left after two minutes' immersion. It is evident that about 260 $cm^2$ of galvanized steel surface can be stripped per liter of 50 percent HCl before the solution will no longer provide complete stripping in a two minute period.

The error involved in stripping of galvanized steel by two minute immersion in 50 percent HCl at 25°C because of basis metal attack is shown in Table III.

TABLE III.

Stripping - Attack of Basis Metal

| Specimen Code | Weight Loss 2 Min., 50 Percent HCl, mg. | Weight Loss Add'l. 2 Min. 50 percent HCl, mg | Error in Weight Loss measurement,% |
|---|---|---|---|
| A | 833.4 | 2.1 | 0.3 |
| G | 929.6 | 2.1 | 0.2 |
| ES | 912.3 | 0.4 | 0.0 |
| GA-1 | 609.8 | 1.4 | 0.2 |
| GA-2 | 616.0 | 1.6 | 0.3 |
| GA-3 | 623.3 | 1.1 | 0.2 |
| U | 875.9 | 0.9 | 0.1 |

It is evident from the data of Table III, that the error in weight loss measurements, attributable to basis metal attack is less than 0.3 percent. It should be recognized that even this small error is magnified by the fact that the basis metal was exposed for a full two minute period; under actual stripping conditions, the basis metal would not be exposed to attack until all of the zinc coating has been removed. The error will increase with an increase of temperature of the acid solution.

## Thickness of Coating - Direct Measurement

Galvanized specimens: A comparison of coating thickness obtained on each side of galvanized steel sheet specimens, using magnetic gage or eddy current device, is shown in Figure 4. The solid lines in the figure connect the thickness of each side of a specimen. The correlation of thicknesses from either the magnetic gage or the eddy current method, are considered satisfactory. Perfect correlation is indicated by the dotted line. Most of the thickness measurements were within 15 percent of each other, by the two measuring methods.

Figure 4 shows that there was substantial difference in coating thickness on either side of the same specimen; in some instances the coating on one side approximated double that of the other. This was particularly so of Code A and Code G materials. Code U material was relatively uniform on both sides. Also evident from Figure 4 is that an average coating thickness as calculated from stripping weight loss could be misleading because of differences in coating thickness on the two sides. Although the average galvanize coating thickness of the specimens examined conforms with ASTM Specification A525-71 (19 μm min. for the "Triple Spot Test" or 17 μm, min. for the "Single Spot Test"), the thinner side of some of the specimens would have failed to meet these requirements.

The average coating thicknesses, determined by magnetic gage or eddy current device were compared with thicknesses calculated from stripping data; the results are presented in Table IV and shown in Figure 5. The average thickness of coatings determined from stripping data generally was within 15 percent of the thickness determined by magnetic or eddy current methods. All three methods appear satisfactory for thickness determinations.

Coating thicknesses also were determined by microscopic cross-section techniques. These results were compared to thicknesses indicated by magnetic gage, and presented in Table V. The magnetic gage values were within +27 and -25 percent of the values obtained by the microscopic method.

In the case of Code U material, the coating was found relatively non-uniform, and the magnetic gage measurements were found to correlate better with the portions of the coating indicated thickest by microscopic measurements. Although often used for referee purposes, the microscopic cross-section method is destructive of the material under test, is more tedious, expensive, and is limited in the area under examination.

Diffusion Alloy Specimens: The diffusion, zinc-iron alloy (galvanneal) layer, Code GA, is not measurable by the eddy current method, since the diffusion layer apparently has the same electrical conduc-

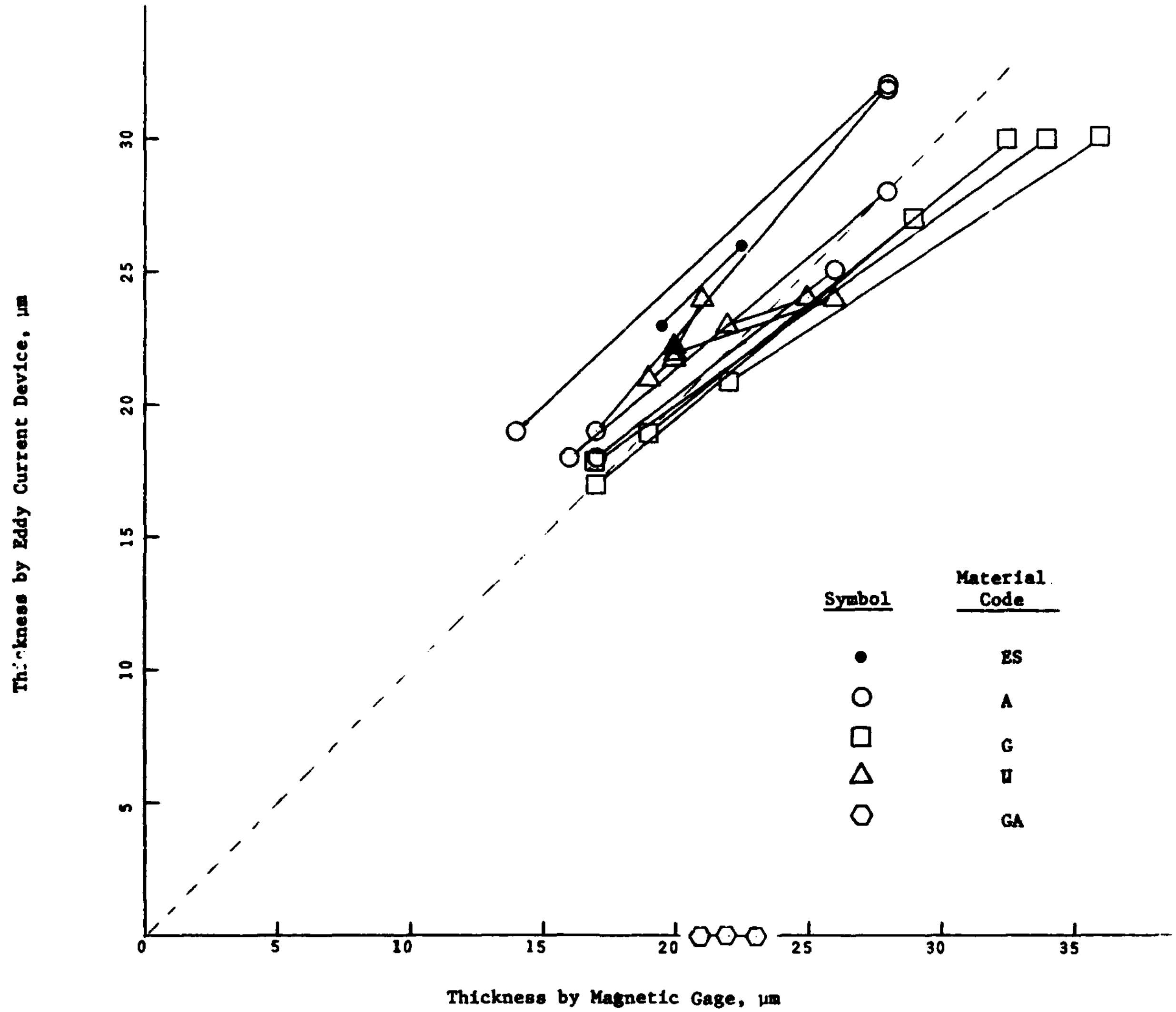



Figure 4. Comparative Thickness of Galvanize Coatings on Steel Using Magnetic and Eddy Current Devices. Lines Connect Thickness Values on Each Side of a Specimen.

TABLE IV.

Galvanize Coating Thickness Measurements by Several Methods

| Specimen Code | Thickness, μm Magnetic Gage Side a | b | Avg. | Eddy Current Side a | b | Avg. | Stripping Avg. |
|---|---|---|---|---|---|---|---|
| A1 | 26 | 17 | 22 | 25 | 18 | 22 | 22 |
| A2 | 28 | 17 | 23 | 32 | 19 | 26 | 24 |
| A3 | 28 | 14 | 21 | 32 | 19 | 26 | 25 |
| A4 | 28 | 16 | 22 | 28 | 18 | 23 | 26 |
| U1 | 26 | 20 | 23 | 24 | 22 | 23 | 23 |
| U2 | 25 | 22 | 24 | 24 | 23 | 24 | 24 |
| U3 | 21 | 20 | 21 | 24 | 22 | 23 | 21 |
| U4 | 20 | 19 | 20 | 22 | 21 | 22 | 21 |
| G1 | 29 | 17 | 23 | 27 | 17 | 22 | 24 |
| G2 | 34 | 17 | 26 | 30 | 18 | 24 | 26 |
| G3 | 36 | 22 | 29 | 30 | 21 | 26 | 27 |
| G4 | 33 | 19 | 26 | 30 | 19 | 25 | 26 |
| GA1 | 23 | 22 | 23 | 0 | 0 | 0 | 17 |
| GA2 | 22 | 22 | 22 | 0 | 0 | 0 | 16 |
| GA3 | 22 | 21 | 22 | 0 | 0 | 0 | 16 |
| GA4 | 23 | 23 | 23 | 0 | 0 | 0 | 17 |
| ES1 | 23 | 19 | 21 | 26 | 23 | 25 | 24 |

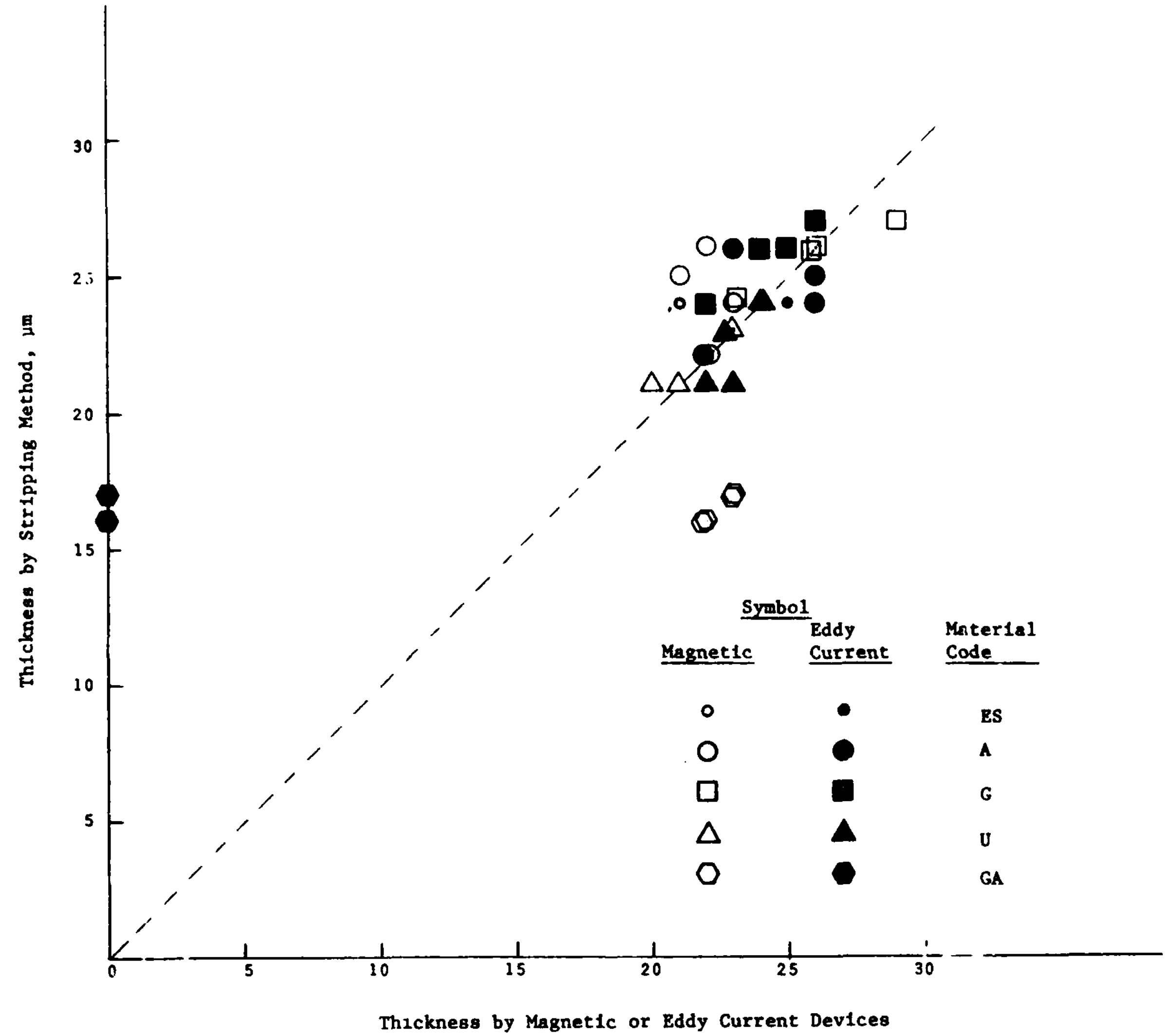



Figure 5. Comparative Thickness of Galvanize Coatings on Steel Using Magnetic or Eddy Current Devices and the Stripping Method

TABLE V.

Galvanize Coating Thickness -
Magnetic Gage vs Cross-Section Measurements

| Specimen Code | Side | Thickness, μm Magnetic Gage | Thickness, μm Microscopic Cross Section | Deviation Percent |
|---|---|---|---|---|
| A | a | 27 | 28 | - 4.5 |
| A | b | 16 | 22 | -25 |
| U | a | 21 | 21 | + 3.7 |
| U | b | 28 | 13 to 26 | ------ |
| G | a | 32 | 26 | +23 |
| G | b | 18 | 14 | +27 |
| ES | a | 20 | 17 | +19 |
| ES | b | 29 | 29 | 0 |
| GA | a | 22 | 25 | -12 |
| GA | b | 21 | 26 | -18 |

tivity as the steel basis metal (Figure 4). The eddy-current method thus evidently can serve as a means of providing a distinction between the zinc and the diffusion alloy layers in galvanize coatings. This could serve as an advantage of this device over the magnetic gage, since the sacrificial protection afforded by galvanized coatings apparently is related to the thickness of the unalloyed zinc layer. If a substantial proportion of coating of the galvanized specimens from any of the suppliers consisted of diffusion alloy, the coating thickness as determined by the eddy current method would be expected to be consistently lower than that determined with the magnetic gage. Since this was not the case, it was assumed that the diffusion alloy layer in the other materials was not of significant thickness.

In this study, the results for the Code GA material (galvanneal) by the microscopic method are of particular interest and value, since they serve to verify the results of the magnetic method, and indicate that the stripping method yielded low values. It is thus indicated that the density of the zinc-iron diffusion alloy is lower than that of pure zinc; the latter was used in all calculations for converting weight loss to thickness of the galvanize coating. From the results obtained, the apparent density of the diffusion alloy coating is calculated to be about 5.3 g/cm$^3$ compared to 7.1 g/cm$^3$ for pure zinc.

## Paint Systems - Adhesion and Salt Fog Test

No incidences of failure occurred with paint systems on Code A and Code G materials; adhesion and corrosion resistance was excellent. In general, the results obtained for painted specimens of Codes B and U materials, were quite good, except for the test involving immersion in water at 35°C for 1000 hours. Specimens in these cases revealed blistering between the topcoat and primer. Results for these tests are summarized in Table VI.

## Corrosion Resistance

At 24 hours' salt fog exposure, galvanized steel panels (10.2 x 15.2 cm), with edges wax-coated, were found to have considerable white corrosion products over the surface. About 25 percent of the surface of the Code G (large spangles) was covered with white salts. Specimens of Codes A, B, ES, and U materials (minimized spangles) were virtually completely covered with white corrosion products. This indicated

TABLE VI.

Paint Adhesion and Salt-Fog Test Results

| Testing Method | Material Code and Observations | | | |
|---|---|---|---|---|
| | A | B | G | J |
| Knife[a] | Adhesion Excellent → | | | |
| Tape, dry[b] | No Removal → | | | |
| Tape, wet[b] | | | | |
| 24 hrs. in $H_2O$ | No Removal → | | | |
| 48 hrs. in $H_2O$ | No Removal → | | | |
| 72 hrs. in $H_2O$ | No Removal → | | | |
| Immersed in $H_2O$, 1000 hrs. | | | | |
| Room temperature (RT) | No Defects → | | | |
| RT, $H_2O$ aerated | No Defects → | | | |
| $35^{o}C$, $H_2O$ aerated | No Defects | Blistered between topcoat & primer | No Defects | Blistered between topcoat & primer |
| Salt-Fog, 1000 hrs. | No paint system defects; no corrosion. | | | |

[a]Method 6304, Federal Test Method, STD 141

[b]Method 6301, Federal Test Method, STD 141

that the surface of Code G material 'rtially was in a passive condition. Galvanneal (Code GA) panels were coated with white salts, but yellow stains were also evident. At 48 hours' exposure, all galvanize coatings were covered with white salts. The galvanneal material also exhibited definite basis metal corrosion in the form of rust spots. At 72 hours' exposure, diffuse yellow stains were visible in the corrosion products of almost all specimens; but, other distinct evidences of basis metal attack, e.g., rust spots, were not discernable. On the other hand, the galvanneal specimens were rusted extensively. At 96 hours' exposure, two of the galvanized steel panels had undergone definite, though slight, basis metal corrosion (Table VII). It is interesting to note that the specimens that failed the corrosion test were not those with least coating thickness. At 120 hours' exposure to salt fog, rust from the underlying steel was evident on five of the minimized spangle specimens.

TABLE VII.

Corrosion Resistance - Salt-Fog Test, Set I

| Source Code | Coating Thickness, µm (Magnetic Gage) | Basis Metal Corrosion (Hours) 72 | 96 | 120 |
|---|---|---|---|---|
| A1 | 24 | 0 | 0 | I |
| A2 | 29 | 0 | 0 | 0 |
| A3 | 16 | 0 | I | R |
| A4 | 25 | 0 | 0 | 0 |
| G1 | 15 | 0 | 0 | R |
| G2 | 36 | 0 | 0 | 0 |
| G3 | 23 | 0 | I | R |
| G4 | 20 | 0 | 0 | 0 |
| U1 | 23 | 0 | 0 | I |
| U2 | 28 | 0 | 0 | 0 |
| U3 | 29 | 0 | 0 | 0 |
| U4 | 25 | 0 | 0 | 0 |
| GA | 22 | R | R | R |

0 = None
I = Incipient rusting
R = Rust evident

It is evident that a 120 hour corrosion resistance test is too severe a performance requirement for this class of galvanized steel, since materials, typical of those which are supplied by the three commercial sources represented, failed to pass. Galvanneal coatings apparently do not provide the level of sacrificial protection attainable with the usual galvanize coatings, compared on an equivalent thickness basis.

The results of salt fog tests conducted on another group of specimens similar to those described above are shown in Table VIII. All passed the corrosion test after 72 hours; four of the 16 panels exhibited definite basis metal corrosion at 96 hours' exposure. All the panels that failed the corrosion test after 96 hours' salt exposure were found to have galvanize thickness of 20 µm or lower. However, five panels of the group with coatings of 20 µm or less, passed the corrosion test. Results of the corrosion test, thus, do not correlate reliably with coating thickness. At least one specimen, in three of the four groups represented, failed this corrosion test.

TABLE VIII.

Corrosion Resistance - Salt-Fog Test, Set II

| Source Code | Coating Thickness, µm (Magnetic Gage) | Basis Metal Corrosion (Hours) 72 | 96 |
|---|---|---|---|
| A1 | 20 | 0 | 0 |
| A2 | 22 | 0 | 0 |
| A3 | 27 | 0 | 0 |
| A4 | 15 | 0 | R |
| B1 | 18 | 0 | 0 |
| B2 | 18 | 0 | R |
| B3 | 19 | 0 | 0 |
| B4 | 21 | 0 | I |
| G1 | 28 | 0 | 0 |
| G2 | 19 | 0 | I |
| G3 | 21 | 0 | 0 |
| G4 | 28 | 0 | 0 |
| U1 | 19 | 0 | 0 |
| U2 | 29 | 0 | 0 |
| U3 | 23 | 0 | 0 |
| U4 | 30 | 0 | 0 |

0 = None
I = Incipient rusting
R = Rust evident

A group of 10.2 x 15.2 cm and another group of 10.3 x 30.5 cm panels from a single source (Code A), with edges waxed or not waxed in each group, were found free from basis metal corrosion after 72 hours' salt-fog exposure. After 96 hours' exposure, basis metal corrosion was evident on half of the specimens tested. The failed panels were approximately evenly divided between those with waxed or wax-free edges and between those 15.2 or 30.5 cm long. Waxed edges, compared with wax-free edges, had virtually no influence on the overall corrosion. After the exposure, the specimens with no wax were in virtually the same condition as those which had been waxed. Comparative results are presented in Table IX.

TABLE IX.

Corrosion Resistance vs Thickness of Galvanize Coating

| Source Code | Panel Length, cm. | Edge | Coating Thickness, µm (Magnetic Gage) | Metal Corrosion, Rating, (Hours) 72 | 96 |
|---|---|---|---|---|---|
| A1 | 15.2 | W | 14 | 0 | I |
| A2 | 15.2 | W | 18 | 0 | R |
| A3 | 15.2 | W | 22 | 0 | 0 |
| A4 | 15.2 | W | 25 | 0 | 0 |
| A5 | 15.2 | N | 15 | 0 | I |
| A6 | 15.2 | N | 18 | 0 | I |
| A7 | 15.2 | N | 24 | 0 | 0 |
| A8 | 15.2 | N | 27 | 0 | 0 |
| A9 | 30.5 | W | 14 | 0 | R |
| A10 | 30.5 | W | 17 | 0 | 0 |
| A11 | 30.5 | W | 22 | 0 | 0 |
| A12 | 30.5 | W | 26 | 0 | 0 |
| A13 | 30.5 | N | 13 | 0 | R |
| A14 | 30.5 | N | 17 | 0 | R |
| A15 | 30.5 | N | 20 | 0 | R |
| A16 | 30.5 | N | 29 | 0 | 0 |

W = Waxed
N = Not waxed
0 = None
I = Incipient rusting
R = Rust evident

Corrosion of the longer panels was unmistakably heavier on the lower portion of the surface. This could be attributed to the fact that with the larger specimens, the lower area was in contact with approximately double the quantity of rundown than comparable areas in the shorter specimens, and that the alkaline character of the corrosion products of the zinc primarily contributed to the condition. On the basis of these findings, it appears advisable to limit the length of the salt-fog test specimens to the 15.3 cm length.

Specimens which failed the corrosion test were those having zinc coatings of 15 to 18 μm, whereas those which were accepted as satisfactory had coatings averaging 24 μm. There were some inconsistencies: a panel with a 17 μm coating passed the test while one of 20 μm failed. From the results obtained with each commercial material, a corrosion test extending to 96 hours was considered too severe.

Bent and straight specimens were subjected to salt-fog for up to 120 hours, and were examined periodically. The corrosion resistances of the sets were compared. No significant differences in the results was observed.

Spot and bead-welded specimens, exposed to salt-fog up to 96 hours, exhibited light rust at weld areas as early as 24 hours. The light rust condition persisted to about 72 hours, but the rust intensified with continued exposure. The condition of the zinc-coated surfaces, away from the welds were essentially as those of other, previously described specimens for equivalent times of exposure in salt-fog.

## Inter-Laboratory Tests

The galvanize coating thicknesses, each side of a specimen, were independently measured at each laboratory, using electrical or magnetic instruments, and are compared in Table X.

Results of salt-fog tests, performed at Coatings and Chemical Laboratory and this laboratory, on 10.2 x 15.2 cm specimens (cut halves of 10.2 x 30.5 cm panels) of each of four materials of six being investigated, are given in Tabls XI. All panels tested at PDL survived the 96 hours salt-fog exposure without evidence of basis metal corrosion. The companion set of panels tested at CCL, resulted in one specimen with evident rusting and another with incipient rust spotting.

In general, the reproducibility and agreement between the laboratories was good. The variations in average thickness with and among specimens is characteristic of the galvanize coating on commercial sheet. This will differ from point to point on the same surface at close regions, and wider variations from side to side of the same sheet.

TABLE X.

Inter-Laboratory, Galvanize Coating Thicknesses

Average Coating Thickness, μm

| Source Code | Side | CCL G.E. Type B* | CCL Elcometer** | FA Magnetic Gage | FA Eddy Current Device |
|---|---|---|---|---|---|
| A | a | 27 | 26 | 27 | 29 |
| A | b | 13 | 13 | 16 | 18 |
| B | a | 12 | 13 | 21 | 19 |
| B | b | 14 | 13 | 19 | 17 |
| ES | a | 28 | 27 | 27 | 26 |
| ES | b | 27 | 28 | 23 | 29 |
| G | a | 36 | 37 | 29 | 28 |
| G | b | 23 | 24 | 18 | 16 |
| GA | a | 18 | 14 | 22 | 0 |
| GA | b | 19 | 14 | 21 | 0 |
| U | a | 20 | 22 | 22 | 23 |
| U | b | 25 | 25 | 27 | 27 |

*General Electric

**Gardner Instruments

TABLE XI.

Inter-Laboratory, Corrosion Resistance - Salt-Fog Test

| | Exposed at CCL | | Exposed at PDL | |
|---|---|---|---|---|
| Source Code | Deposit Thickness, µm Magnetic Gage | Basis Metal Corrosion, 96 hours | Deposit Thickness, µm Magnetic Gage | Basis Metal Corrosion, 96 hours |
| A1 | 19 | 0 | 18 | 0 |
| A2 | 18 | 0 | 19 | 0 |
| A3 | 23 | 0 | 24 | 0 |
| A4 | 25 | 0 | 23 | 0 |
| B1 | 20 | 0 | 20 | 0 |
| B2 | 21 | 0 | 22 | 0 |
| B3 | 23 | 0 | 22 | 0 |
| B4 | 20 | 0 | 22 | 0 |
| G1 | 30 | 0 | 33 | 0 |
| G2 | 23 | 0 | 18 | 0 |
| G3 | 31 | 0 | 36 | 0 |
| G4 | 17 | 0 | 16 | 0 |
| U1 | 16 | R | 19 | 0 |
| U2 | 21 | 0 | 23 | 0 |
| U3 | 22 | I | 22 | 0 |
| U4 | 25 | 0 | 23 | 0 |

0 = None
I = Incipient rusting
R = Rusting

## Formability

Each material (all codes) was amenable to sharp bending. None of the zinc coated specimens including the galvanneal (GA) specimens, exhibited any sign of failure as a result of being bent through 180°.

## Welding

Spot welding was effectively accomplished on materials A, B, G. Material U was weldable but presented some difficulties. With this, the weld spot diameter was consistently above the goal minimum of 0.24 inch (ca. 6 mm) and the weld strength was slightly less than the required minimum of 1150 kg. (2500 lbs.), ranging between 909 kg. (2000 lbs.) to 955 kg. (2100 lbs.). Attempts to produce higher torsion shear strength in the weld by increasing the current over 13,500 amperes caused excessive metal expulsion.

Gas-metal arc welding of materials A, B, G, and U was readily accomplished. Material B tended to produce an irregular bead shape more than did the other materials. This condition appraently was related to the effect of the carbon dioxide shielding gas and different emanation of zinc vapor, contributing to some instability of the arc and more spatter.

The back surfaces of the panels evidenced melting of the zinc coating from the heat of welding, but the zinc resolidified and no breaks in the coating were observed. Bead welds were made with panels backed by a flat copper plate and using the short-circuiting technique to minimize loss of zinc.

Shielded metal arc welding of materials A, B, G, and U was easily accomplished. Material G seemed to be more sluggish in fusing, and the welder had to dwell slightly longer for this to occur properly, but the bead, once fused, ran quickly. Hence, the resultant weld bead, on the G material, was somewhat wider than that obtained with A, B, or U. These specimens were welded against a copper backup to minimize loss of zinc on the underside of the panel. Although some fusion and resolidification of the zinc occurred on the back surface, the coating under the weld was continuous.

# CONCLUSIONS

1. Minimized spangle galvanized steel from various sources varies considerably in appearance, but is readily distinguishable from ordinary galvanized steel. Generally, the crystal face in minimized spangle material is approximately 1 mm, maximum dimension. In some materials, distinct crystals are not evident to the unaided eye.

2. The thickness of galvanize coating on steel can be determined satisfactorily and with good agreement by:

a. stripping the coating, as prescribed, and calculating the thickness from the weight of the stripped coating.
b. magnetic gage.
c. eddy-current gage. This means is unsuitable for measuring the thickness of iron-zinc, diffusion-alloy coatings.

Good correlation exists between valued obtained by stripping, or by cross-section, microscopic methods, and those acquired using a magnetic gage. There is close agreement between the magnetic gage and eddy-current values.

The thickness of the galvanize coatings on steel, designated 1.25 Commercial, ranges from ca. 14 to 36 μm. Further, the coating on each side of the sheet material can differ, and in some cases by a factor of approximately two.

3. In salt-fog, the corrosion resistances of 1.25 Commercial galvanized steels from different sources essentially are equivalent, and are independent of spangle size, or surface smoothness. Galvanneal (zinc-iron diffusion alloy) coating on steel offers significantly less protection to the basis metal than does the usual galvanize coating.

4. Severe bending of the various galvanized steels is not damaging to the metallic coatings, and does not adversely affect corrosion resistance.

5. Paint adhesion to prepared surfaces of the various galvanized steels is excellent.

6. Spot or bead-welding of the various 1.25 Commercial galvanized steels is readily accomplished. Virtually no compromise of corrosion resistance occurs because of welding.

7. The corrosion resistance, in salt-fog, of 1.25 Commercial galvanized steel (coating thickness, 14 to 36 μm) is roughly but not directly correlatable to the thickness of the coating.

8. Test conditions and performance characteristics of 1.25 Commercial galvanized steel from different sources, have been defined adequately for specification preparation purposes.

## RECOMMENDATIONS

1. Commercial galvanized steel sheet, ca. 18 μm minimum coating thickness, preferably of minimized spangle and smooth finish, is recommended for use in automotive vehicle bodies.

2. Magnetic or eddy-current gages are recommended to be used more widely, instead of the stripping method, for establishing the thickness of the galvanized coating on steel sheet.

3. Eddy-current devices do not indicate thickness of zinc-iron diffusion, therefore they are suggested to be employed along with magnetic gages to establish the thickness of the zinc stratum of the coating.

4. For ascertaining the corrosion resistance of 1.25 Commercial galvanized steel, an exposure to salt-fog not to exceed 76 hours is recommended. Diffuse yellowish staining of the white surface is to be expected, and not be cause for rejection, whereas the presence of rust spots or streaks is cause for rejection.

5. A recommended size of specimen for salt-fog testing is 10.2 x 15.2 cm.

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